Runoff System Model in Snow Accumulation and Melting Seasons

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Abstract

The model making in the snow accumulation and melting seasons may be dealt with with the series of the following system. Snowfall→Transformation System I→Snowpack→Transformation System II→Snowmelt→Tranformation System III→Streamflow. The snowmelt and runoff system models developed in this study are primarily concerned with considering the above processes on as physical a basis as possible and at the same time best representing those processes in light of practical modelling considerations according to available data.

As for the snowfall and the transformation system I, firstly, the observed data of depth of snow are directly introduced into the model. As for the transformation system II, in addition to the temperature index method the heat budget considerations are partly introduced into the model. And moreover the behaviour through the snowpack of the water melted or frozen by the heat transfer is introduced on a physical basis in order to make the model more rational. As for the transformation system III, the statistical unit hydrograph method proposed previously is expanded to the snow accumulation and melting seasons with some modifications. Lastly the above models are applied to the Kuzuryu River, in particular. For the very heavy snowfall of 1981 the sequence of inflow into the dam up the river are estimated.

1. Introduction

The increase and uneven distribution of water demand require the effective and efficient utilization of river flow. In particular there is much differnece in the distribution of water demand and water resource between regions along Pacific sea side and Japan sea side. A large amount of snow in the regions along the Japan sea side is attractive as a water resource. It is necessary to do research on the snowmelt and runoff processes in order to utilize the snow as a water resource.

In general, because of the relative inaccessibility of catchment area and the difficulty of observation, the model making based on the knowledge of the physics of snow has made slower progress than that of the rainfall-runoff system.

The model making in the snow accumulation and melting seasons may be dealt with with the series of the following system[1]. In this case, the transformation system represents the operation performed by the system on the input and the throughput in order to transfer them into output.

snowmelting factors
↓
snowfall → transformation system I → snowpack → transformation system II —┐
stream flow ← transformation system III ← snowmelt ←┘

Where the transformation system I mainly describes the snow accumulation process and renews the depth of snow based on the addition of the new snow and reduction in depth of the old pack due to its compaction. The transformation system II describes the process where the heat from radiation, rainfall and ground etc. transfers to the snowpack. In consequence, the water melted on the snow surface percolates through the snowpack and reaches the ground surface. Lastly, the transofmration system III describes the process where the snowmelt water which reached the ground surface discharges into the river as the overland, interflow and groundwater runoffs.

The snowmelt and runoff system models developed in this study are primarily concerned with considering the above processes on as physical a basis as possible and at the same time best representing those processes in light of practical modelling considerations according to available data.

The data for the snowfall and the transformation system I, that is to say, the observed data of depth of snow, are directly introduced into the models. As for the transformation system II, in addition to the temperature index method such as Degree day or Degree hour the heat budget considerations are partly introduced into the model. And the behaviour through the snowpack of the water melted or frozen by the heat transfer is introduced on a physical basis in order to make the model more rational. As for the transformation system III, the statistical unit hydrograph method proposed previously is expanded to the snow accumulation and melting seasons with some modifications. Lastly the above models are applied to the Kuzuryu River and for the very heavy snowfall of 1981 the sequnece of inflow into the dam up the river are estimated.

2. Spatial and time distribution of depth of snow

The above processes and their model making must be described according to a daily time interval in order to estimate the amount of daily runoff continously during the snow accumulation and melting saesons, not limiting to the problem of forecasting the total volume of spring runoff.

When we estimate the depth of snow in the daily time interval through the observation of snowfall and the transformation system model, we must consider the addition of new snow and reduction in depth of the old snowpack due to its compaction. In addition, we are afraid of the inadequacy of the model in areas of high elevation where there are no data.

When we consider the common situation where there are some stations observing the depth of snow in spite of its difficulty and we emphasize estimating the depth of snow, we had better estimate its spatial and time distribution in a direct form based on the observed data rather than through the transformation system model.

Though in the recent years observation systems such as Landsat and aerial photographic survey have been developed and offer attractive information concerned with the areal distribution of snowpack, their availability is limited to a given location and time and they have some problems in accuracy for estimating the depth of snow. So we propose the method of utilizing the data of depth of snow observed at some stations.

The topographic factors such as elevation, slope, aspect, exposure, distance from seashore and vegetation, then, influence the spatial distribution of depth of snow. Among them perhaps the most important factor is elevation. Elevation has significant effects on the amount and distribution of precipitation and variation in surface temperature, and hence the distribution of depth of snow.

At first, therefore, we investigate the relationship between the depth of snow observed at several points and their elevation, where the depth of snow is observed at nine o'clock in the morning day by day. **Fig. 1** shows the location of observation stations and **Table 1** shows the observed data. The period for analysis is from Dec. 1, 1980 to Mar. 31, 1981 and the number of days is 121 days. **Fig. 2** shows the daily variation of correlation coefficient between the depth of snow and elevation. And **Figs. 3** and **4** show the daily variation of parameters α and β estimated by

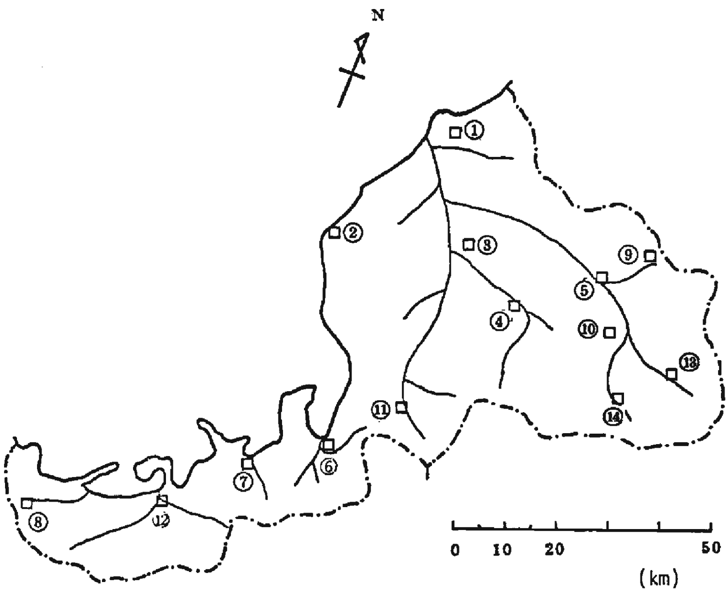

Fig. 1. Location of observation stations.

Table 1. Observed data used in the model.

station name	mikuni	koshino	fukui	miyama	katsuyama	tsuruga	mihama	kawakami	kitadani	ohno	imajyo	obama	kuzuryu	managawa
station no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
elevation(m)	80	30	9	60	126	1	10	75	440	175	160	10	569	393
distance from seashore(km)	1.0	0.1	15.8	26.0	35.2	0.4	1.0	5.4	34.4	40.4	8.8	4.4	68.6	49.6
temperature	-	-	o	-	o	-	-	-	-	o	o	-	o	o
snow's depth	o	o	o	o	o	o	o	o	o	o	o	o	o	o
precipitation	-	-	o	o	o	-	-	-	-	o	-	-	o	-
snow's density	-	-	o	-	-	-	-	-	-	-	-	-	-	-

o : observed data, - : no data

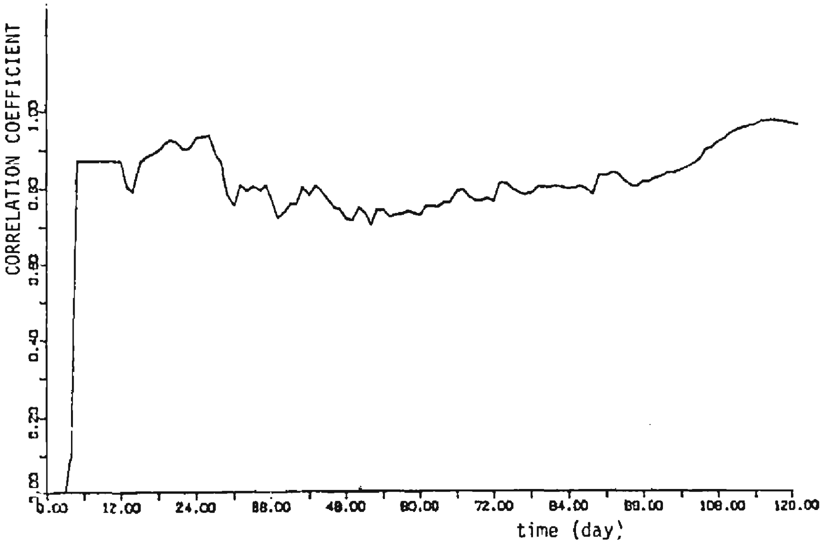

Fig. 2. Daily variation of correlation coefficient between snow's depth and elevation.

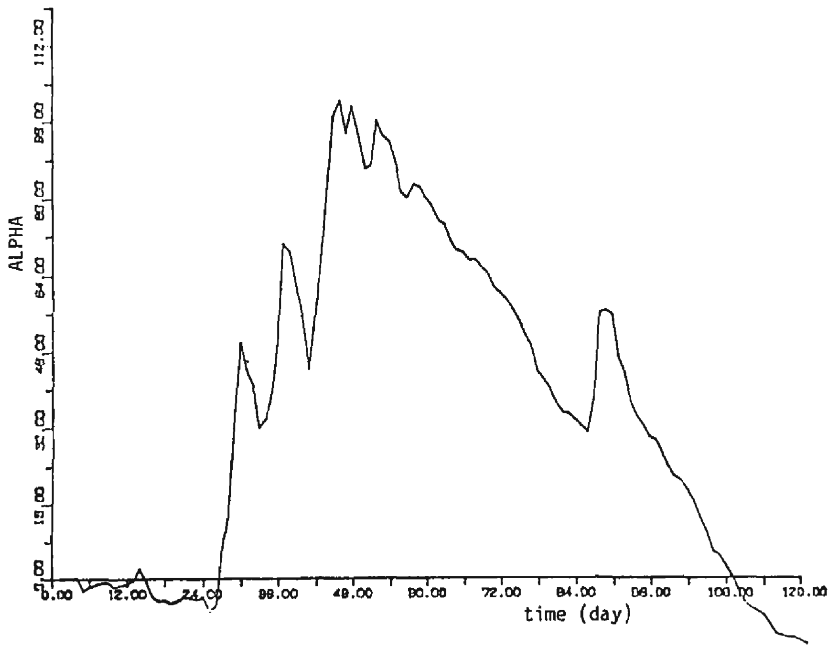

Fig. 3. Daily variation of parameter α.

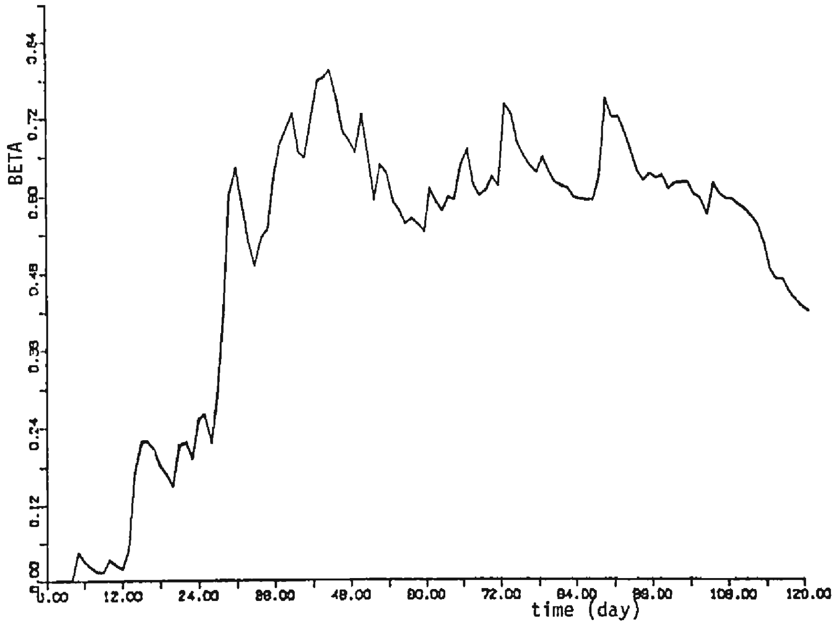

Fig. 4. Daily variation of parameter β.

method of least squares, respectively ($Y_{ij}=\alpha_i+\beta_i X_j$ ($i=1, 2, \cdots, 121$), Y_{ij}; depth of snow at j-th location and i-th day in centimeters, X_j; elevation of j-th location in meters).

Though no correlation shows up till the middle of Decmeber because of no snowpack in most locations, the correlation coefficient hereafter is higher than 0.8. The parameter α expresses the depth of snow at elevation zero and its pattern is representative of time distribution of depth of snow at all locations. The variation of parameter β has the tendency to increase in the early stage of snowfall and in the stage of snow accumulation after that, becoming stable in the continuous stage of snow accumulation and then decreasing in the snowmelt stage. The multi-correlation analysis of elevation, distance from seashore and depth of snow shows the increase in explanation of estimation of depth of snow. In that case, however, the depth of snow necessary for estimating the amount of snowmelt must be expressed in two dimensional coordinates such as elevation and distance from seashore.

Judging from the degree of increase in explanation, the depth of snow can be estimated by simple correlation based only on elevation. By the way, the depth of snow estimated by the above simple correlation shows good agreement with the observed data in some cases at Kuzuryu and Managawa dams at higher elevations.

3. Development of snowmelt and runoff system models

The snow accumulation process can be described with the spatial and time distribution of depth of snow as mentioned in chapter **2**. In this chapter the model making of the snowmelt and runoff processes is described.

3.1. The effect of the addition of heat to the snowpcak

The total heat flux applied to the snowpack to induce snowmelt can be expressed as follows.[2)]

$$H = H_{rs}+H_{re}+H_{cv}+H_{cn}+H_r+H_g \tag{1}$$

where H_{rs}; absorbed shortwave radiation, H_{re}; net longwave radiation exchange between the pack and its environment, H_{cv}; convective heat transfer from the air above, H_{cn}; heat supplied by condensation, H_r; heat content of rainfall, H_g; conductive heat from the ground.

Of these components, the heat content of rainfall in t-th day interval, $HR(t)$, is represented by eq. (2).

$$HR(t) = TR(t)*R(t) \tag{2}$$

where $TR(t)$ is the temperature of rainfall in the same day, estimated using the air temperature by assuming that they are equal and $R(t)$, the amount of rainfall in centimeters.

When the precipitation did occur, it is necessary to establish whether the precipitation was rain or snow. This decision is made on the basis of the current air temperature. When the daily average air temperature is higher than 1°C (shown later), the precipitation is rain. In this study, however, the above criterion was used only in the period of March and in other periods only the variation of depth of snow was introduced into model without considering the form of precipitation. The heat transfer from the ground was assumed to be constant throughout the snow season. This constant value has been estimated through the comparison of the observed and the computed daily stream flows.

In situations where there is not sufficient data to estimate the total effect of remaining components, the temperature of the air is used as an index of those components. The procedure used in this study is to use the temperature as an index to the heat transferred for snowmelting with some accounts for radiation, that is,

$$HM(t) = T1(t)*DM(t) \tag{3}$$

where $HM(t)$ is the net heat transferred for snowmelting except the heats of rainfall and from ground, $T1(t)$, the cumulative value in the daily time interval of air temperature more than 0°C being computed from the hourly air temperature and $DM(t)$, the melt factor in the t-th day, respectively· The reason that measured the temperature index in degree-hour not in degree-day comes from the introduction of the effect of the variation of air temperature within the day into model, as described later. Though equation (3) is not actually the case since intense shortwave radiation on a clear winter day may produce melt when the air temperature is less than 0°C, in the absence of data to estimate its effect the cumulative value of air temperature more than 0°C will give a reasonable estimate of the melt over short term periods such as daily time intervals.

The change in the melt factor or the degree hour factor is influenced by the variations of the incident shortwave radiation and albedo of snow surface. Moreover the following adjustments are made.[3)]

$$DM(t) = \gamma * FR(t) * (1.0 - AL(t)) \tag{4}$$

where γ is the degree-hour factor for the most intense spring insolation and one of identified parameters, $FR(t)$, an adjustment for the variation of incident shortwave radiation over the season as given by the ratio of the insolation at a given location and time to the insolation at the most intense spring time and $AL(t)$, the time variation in albedo of snow surface, respectively.

On the other hand, since the heat transferred in the frozen process through the nightly low temperature is assumed to be large in the period of the snow accumulation and small in the period of snowmelt, the following expressions are developed on a basis of the cumulative value of air temperature less than 0°C.

$$HC(t) = T2(t) * DC(t) \tag{5}$$

$$DC(t) = (C - DM(t)) * CR \tag{6}$$

Where $HC(t)$ is the heat transferred for the frozen process, $T2(t)$, the cumulative value in the daily time interval of air temperature less than 0°C being computed from the hourly air temperature and $DC(t)$, the frozen factor in the t-th day, respectively. C is the constant being identified and CR is the ratio of the nightly radiation to the daily radiation. No seasonal variation of CR is assumed because the nightly radiation is smaller in absolute value than the daily radiation.

3.2. Spatial and time distribution of the cumulative values of air temperature more or less than 0°C

As noted in chapter **2**, elevation plays a very significant role in the spatial variability of air temperature. Spatial variation, due to elevation effects, of variables such as the cumulative values $T1$ and $T2$ may be accounted for in the following way;

At first, in the period from Dec. 1 to Mar. 31 the hourly data of air temperature are collected at the gauge stations such as Imajyo, Fukui, Ohno, Katsuyama, Kuzuryu and Managawa dams shown in **Fig. 1.** Secondly the daily cumulative values $T1(t)$ and $T2(t)$ of air temperature more or less than 0°C are computed at each station from those hourly data. And then the same procedure as the estimation on the spatial variability of depth of snow, that is, correlation analysis is implemented day by day for those computed $T1(t)$, $T2(t)$ and their elevation. Lastly the spatial and time distribution of daily variables $T1$ and $T2$ are estimated at higher elevations through the correlation equations identified each day.

Applying the results of this procedure to Kuzuryu River Basin shows that both variables $T1$ and $T2$ have negative correlation to elevation and their correlation

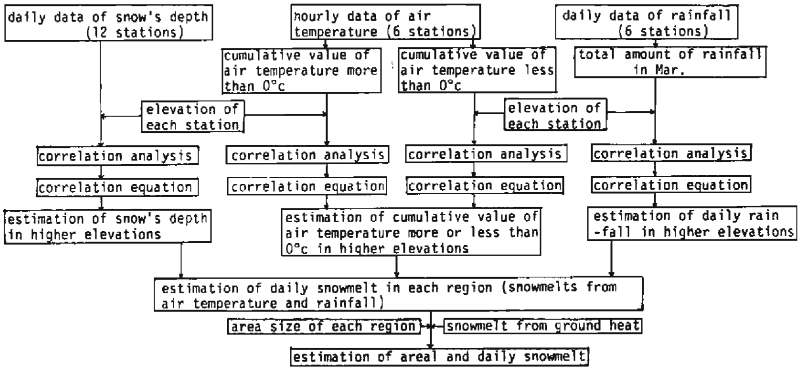

Fig. 5. Flow chart for estimating the snow's depth, air temperature and rainfall in higher elevations.

coefficients are more than 0.75, in the absolute value.

Fig. 5 is the flow chart that shows each procedure considered in this section. This information becomes the input data for the snowmelt model described in the next section.

3.3. Snowmelt model

(1) Liquid water content transformed from added heat

Once the index for net total heat transferred only by air temperature for snowmelt or frozen process is estimated day by day through the procedure described above, it is possible to express the effect of this heat on the snowpack in terms of the number of centimeters of liquid water that may be melted or frozen by this amount of heat.

This quantity is given by eq. (7) because 80 cal/cm^2 are required to produce one centimeter of water from pure ice at 0°C.

$$MS(t) = HS(t)/80 \tag{7}$$

The heat transfer from rainfall being added to the above quantity, the total quantity transferred for snow melting is,

$$TMS(t) = (HS(t)+HR(t))/80 \tag{8}$$

The heat transfer from the ground is assumed to be constant during the snow accumulation and melting seasons aside from the above quantity $TMS(t)$.

(2) Liquid water storage and liquid water holding capacity

Since the effect of the addition of heat to the snowpack is to produce melt as discussed above, there will be an increase in the stored liquid water in the snow. Provided that the behaviour of melted water throughout the snowpack resembles the behaviour of rain water throughout the soil layer, the amount of liquid water that the snowpack can hold as storage is limited by its liquid water holding capacity, *WHC*[4]. If the liquid water stored in the snowpack at any time exceeds the value of *WHC*, the excess can no longer be held against gravity and begins to percolate through the snowpack and eventually will reach the ground to become runoff. Otherwise the liquid water equivalent is stored in the snopwack.

And then it is assumed that the melted water percolates throughout the snowpack and reaches the ground within that day.

The problem is to determine the liquid water holding capacity of snow *WHC*. It is, however, not possible to determine *WHC* theoretically because of its complex process in the snow accumulation and melting seasons. Then, in this model the value of *WHC* was determined on a basis that has correlated it with the density of snow, *SD*. Its value over various density ranges was given with reference to equations proposed by Amorocho and Espildora[5] (**Fig. 6**).

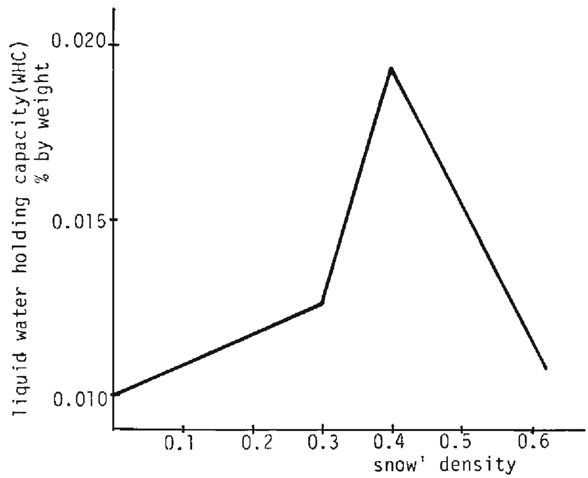

Fig. 6. Variation of WHC with snow's density.

$$\begin{aligned} WHC &= 0.008*SD+0.01 \quad ; SD<0.3 \\ WHC &= 0.066*SD-0.007; \ 0.3\leq SD<0.4 \\ WHC &= -0.037*SD+0.034; \ 0.4\leq SD \end{aligned} \tag{9}$$

As the above value is given in terms of % by weight, it is converted into the liquid water equivalent by multiplying the above *WHC* by depth and density of snow.

On the other hand, the cumulative value of air temperature less than 0°C that occurs mainly in the night is added to the snowpack, and some of the liquid water in the snowpack is frozen. The quantity is given by

$$WC(t) = H(t)/80 \tag{10}$$

and this quantity is subtracted from the liquid water in the snowpack.

In consequence, the melted water of the next day must first be applied to replace this subtracted quantity and then if the remaining liquid water stored exceeds the

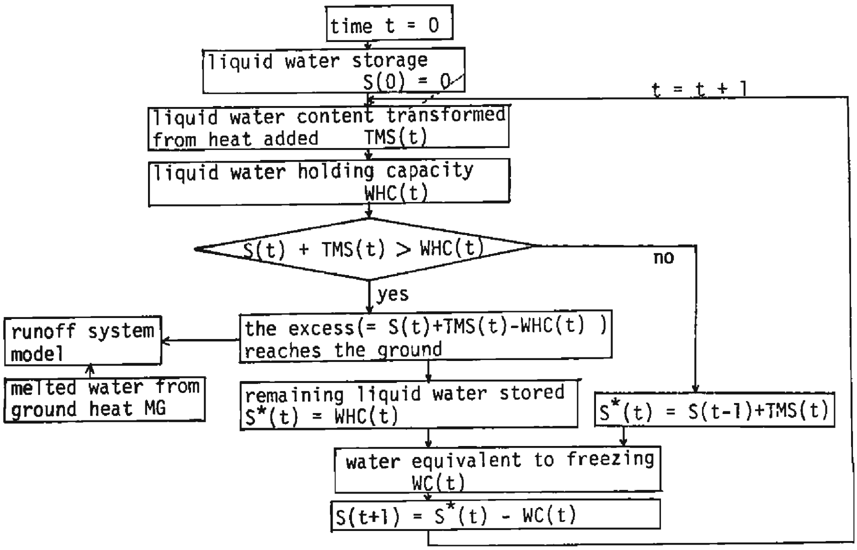

Fig. 7. Total flow representing the estimation of daily snowmelt.

value of *WHC*, the excess will reach the ground to become runoff.

Fig. 7 represents the total flow of the above procedures. These procedures being repeated continously over time, the amount of water that reaches the ground to become runoff may be computed day by day.

3.4. Runoff system model

The sum total of the melted water induced by heat transfer from the ground and the amount of melted water reaching the ground computed in section **3.3** is input into the runoff system model for computation of the resulting streamflow.

As for the runoff system model on the basis of daily time interval, several models have been developed. In this study the statistical unit hydrograph method[6] was applied to the runoff system in the snow accumulation and melting seasons. This model computes the daily streamflow through the unit-impulse response function (we have designated this as 'Statistical Unit Hydrograph') derived from Wiener-Hoph equation after time invariant linearization of the runoff system being made based on the physical behaviour of the runoff phenomena.

Since the ground is mostly covered by snowpack in the snow accumulation and melting seasons, then, it seems to be able to assume that the soil moisture holds at least the capillary saturated water content. As the sum total of melted water may be considered to be equivalent to the amount of rainfall in the rainy season from point of physical meaning, we proposed the following allocation rule for practical purposes.

After the sum total of melted water is added to the existing soil moisture in runoff zone, which is defined as the domain between the saturated and the capillary

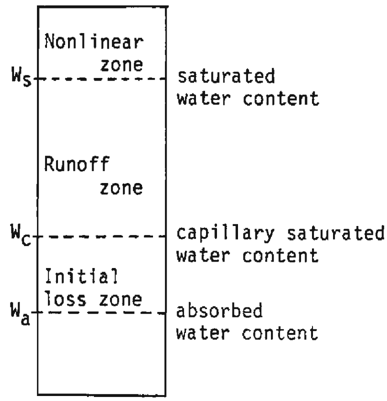

Fig. 8. Schematic diagram of states of water content in the subsurface stratum.

saturated water content, (**Fig. 8**), the decrease of stored soil moisture due to the supply of water to the subsurface and groundwater runoff is represented as follows.

$$W(t) = \{W(t_0)+f_c/\rho\}e^{-\rho(t-t_0)}-f_c/\rho\} \tag{11}$$

where $W(t_0)$ and $W(t)$ are the water content in the porous subsurface stratum at t_0 and t-th days, ρ, the recession coefficient of water content in the runoff zone and f_c, the final infiltration rate, respectively.

Then the daily decrease of soil moisture, $DW(t)$ $(=W(t)-W(t+1))$, is divided into the components $TMS_s(t)$ and $TMS_g(t)$, supplied to the subsurface and groundwater runoffs respectively. In this case because the maximum value of the component supplied to the groundwater runoff is equal to the final infiltration rate f_c,

$$\left.\begin{aligned} TMS_s(t) &= DW(t)-f_c \\ TMS_g(t) &= f_c \end{aligned}\right\} \quad \text{if } DW(t) \geq f_c \tag{12}$$

$$\left.\begin{aligned} TMS_s(t) &= 0 \\ TMS_g(t) &= DW(t) \end{aligned}\right\} \quad \text{if } DW(t) < f_c \tag{13}$$

And then if melted water has exceeded the saturated water content, the excess will be supplied to the surface runoff component.

Lastly we may compute the subsurface and groundwater runoffs $Q_s(t)$, $Q_g(t)$ with the following equations.

$$Q_s(t) = \sum_{\tau=0}^{T_s} h_s(\tau)*TMS_s(t-\tau) \tag{14}$$

$$Q_g(t) = \sum_{\tau=0}^{T_g} h_g(\tau)*TMS_g(t-\tau) \tag{15}$$

where $h_s(\tau)$ and $h_g(\tau)$ are the statistical unit hydrographs of the subsurface and groundwater runoffs. These unit hydrographs are the same as ones in the rainy season and are identified through the flow chart shown in **Fig. 9**.

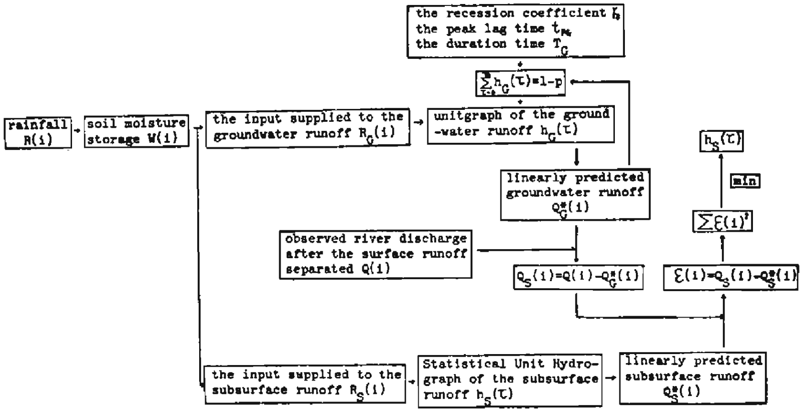

Fig. 9. Flow chart on statistical unit hydrographs of subsurface and groundwater runoffs.

4. Application of the models to the basin of Kuzuryu dam

The snowmelt and runoff system models developed in chapter **3** were applied to the basin of Kuzuryu dam. To test the accuracy of the models the calculated and observed mean daily streamflows were compared at the site of Kuzuryu dam for the 1981 snow accumulation and melting seasons.

The Kuzuryu dam is located at the headwaters of the Kuzuryu River which flows into the Japan sea. It is covered with snow every year, particularly in 1981. The watershed is 184.5 km^2 in area and ranges in elevation from 600 to 1400 meters above mean sea level. The land surface has an average slope of thirty percent. It is covered with coniferous forest and has a fairly permeable A-soil layer.

Though the gauging locations of air temperature and depth of snow and their observation periods have been described previously, there are scarcely any such devices in the study area. The mean daily streamflows into the dam were estimated from the observed data of water level and release from the dam site.

4.1. Data necessary for runing the model

(1) Albedo and adjustment for the variation of incident shortwave radiation

There is no data on these meteorological variables, so the time variation in albedo of a snow surface was taken from U.S. Army Corps of Engineers reports[7] and applied to the whole watershed.

$$AL(t) = 0.85*(0.82)^{t^{0.46}} \tag{16}$$

where t means the age of the snow surface in days.

The adjustment for the variation of incident shortwave radiation was given by the ratio of the mean monthly value of direct insolation observed at Wajima to the most intense springtime, April.

month	Dec.	Jan.	Feb.	Mar.
FR(·)	0.89	0.98	1.00	0.94

(2) Division of the watershed

In order to consider the elevation effect of air temperature, depth of snow and rainfall the watershed was divided into four regions.

region no.	elevation (m)	area (km^2)
1	∼ 800	75.6
2	800∼1000	64.9
3	1000∼1200	36.1
4	1200∼1400	7.9

The daily average snowmelt for each of the above regions is estimated by the procedure described in chapter **3** and then the weighted average of these over the area is input into the runoff system model.

(3) Rainfall in higher elevations

The surface air temperature is an important index for differentiating between rain and snow. As shown in **Fig. 10**, the index temperature is nearly 1°C in the daily average air temperature. So during March it was assumed that precipitation occurs in the form of rainfall whenever the daily average of surface air temperature is more than 1°C.

The relationship between rainfall and elevation was given by the following equation.

$$R(t) = K(t)*(10.0+0.0136*H) \tag{17}$$

Where R is the amount of rainfall in centimeters, H, the elevation measured in meters, $K(t)$, the ratio of t-th day rainfall to the total rainfall of March (they are weighted average of Miyama, Fukui, Ohno and Katsuyama stations.) and t, the age counted from Mar. 1 in days, respectively.

(4) Density of snow

The time variation in density of snow was estimated from the data measured a few times during this period at Fukui (**Fig. 11**). This function was directly applied to the study area.

(5) Runoff system model

The statistical unit hydrographs of subsurface and groundwater runoff systems were identified from the observed data of daily rainfall and mean daily streamflow in the rainy season from Jun. to Nov.. As for the valuse of W_s, W_c and W_a concerned with modelling the distribution of the water content in the A-soil layer, those

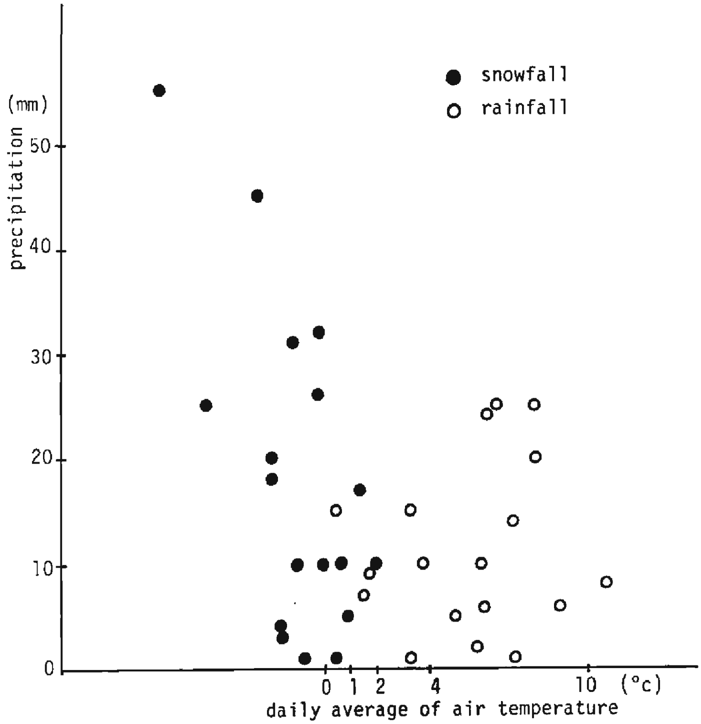

Fig. 10. Index temperature for differentiating of rain and snow.

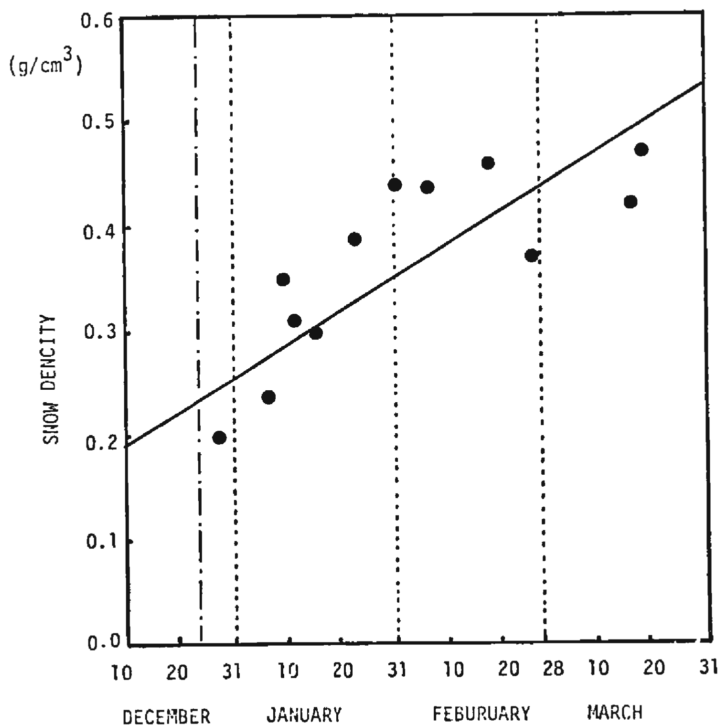

Fig. 11. Variation of snow's density with time at Fukui.

found out at Yura River basin in the neighborhood of study area were used with no modification because of insufficient data. **Fig. 12** shows the statistical unit hydrographs obtained by the above method and **Fig. 13** shows the comparison between the synthesized and observed streamflows in the same period.

They coincide fairly well as a whole except for large floods. Those unit hydrographs, therefore, are applied to synthesize the daily streamflows in the snow

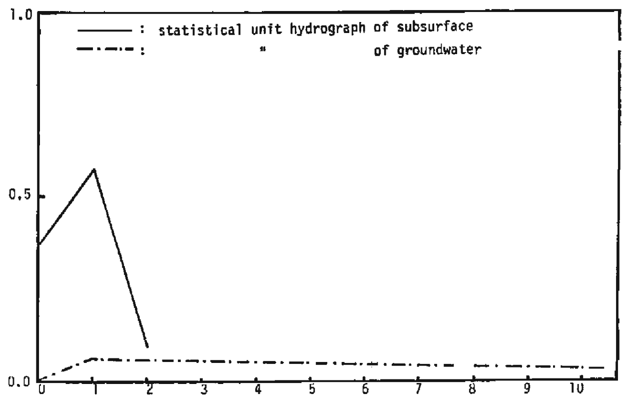

Fig. 12. Statistical unit hydrographs obtained at Kuzuryu dam in the rainy season.

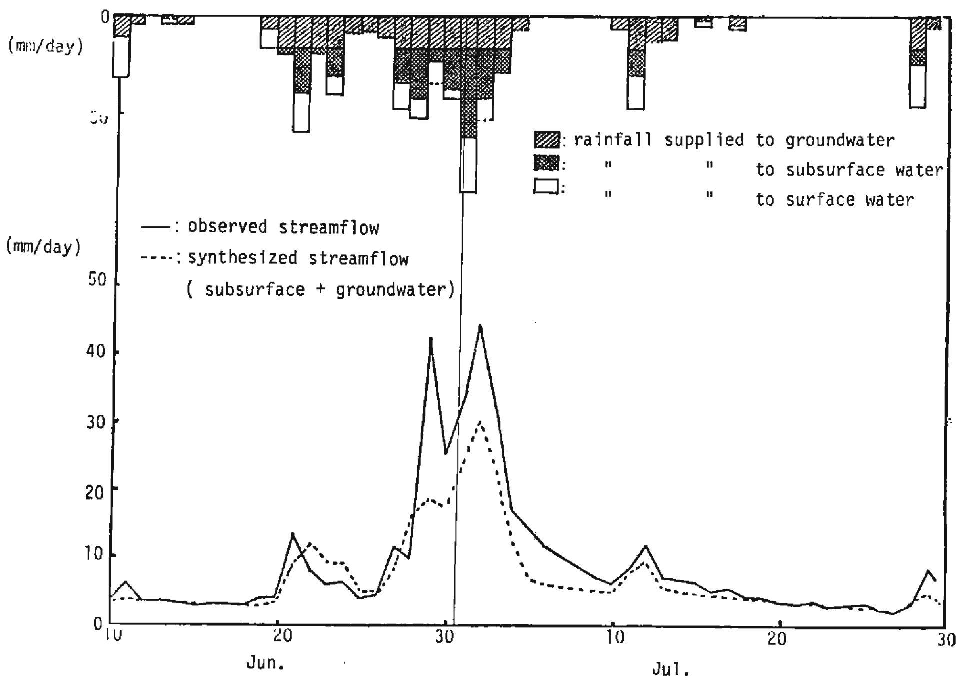

Fig. 13. Comparison between the synthesized and the observed mean daily streamflows at Kuzuryu dam in the rainy season.

accumulation and melting seasons.

4.2. Results and discussion

When the key variables for each region, which are based on the correlation equations between the depth of snow and elevation obtained in chapter **2**, the correlation equations between the cumulative values of air temperature more or less than 0°C and elevation obtained in section **3.2** and the correlation equation between rainfall and elevation obtained in section **4.1**. 3), are estimated continuosly, we may compute the snowmelt continuosly on a daily basis in accordance with the flow chart shown in **Fig. 7**. Then the daily snowmelt computed for each region is transformed to the weighted average that is input into the runoff system model.

For the region 1 that comprises the site of the Kuzuryu dam, **Fig. 14** shows the estimated results of snow depth, *DS*, the cumulative values of air temperature more or less than 0°C, *T*1, *T*2, and rainfall *R* with the observed streamflow into the dam. Although during the snow accumulation season the streamflow into the dam is small in quantity and variation, the increase of snow depth is large. The value of *T*1 is almost zero all the time during the snow accumulation, but it begins to have positive value from the end of Feb.. Inversely the value of *T*2 has tendency to be large in the snow accumulation season and small in the melting season. During Mar. the

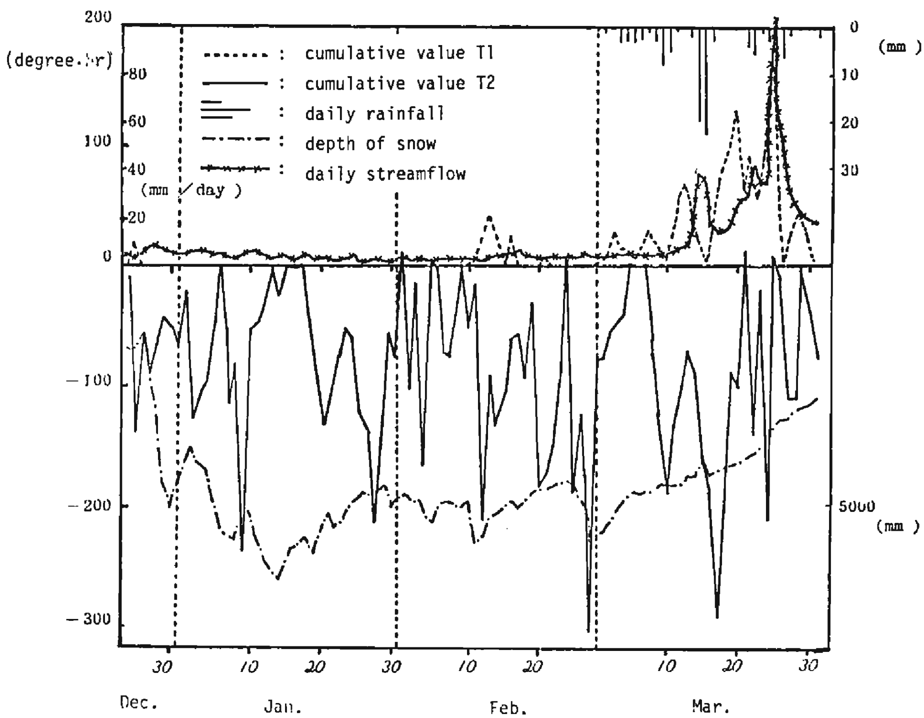

Fig. 14. Synthesized snow's depth, cumulative values of air temperature more or less than 0°C and rainfall.

increase of air tmeperature produces the increase of streamflow into the dam along with rainfall.

Fig. 15 shows the results of weighted average of daily snowmelt for three cases set up in **Table 2**. In each case the variation of daily snowmelt with time has the same tendency. That is, the snowmelt induced by the heat transfer from the ground forms the dominant component in the period from the end of Dec. to the middle of Feb.. During Mar., the increase of air temperature and the addition of rainfall promote the daily snowmelt and produce the variation of daily snowmelt with time. The introduction of *WHC* seems to be relatively small with respect to the daily snowmelt.

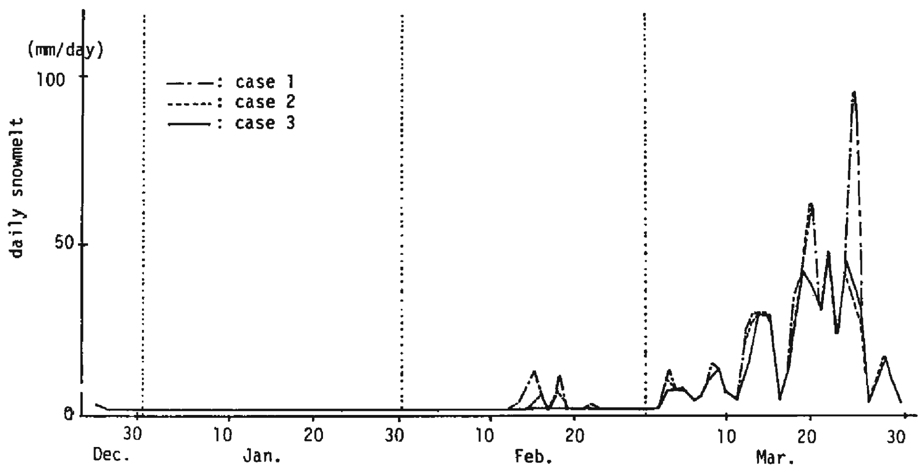

Fig. 15. Comparison among synthesized snomelts for three cases.

Table 2. Assumed parameters for three cases.

case number / parameter	1	2	3
γ (langleys/hr)	48.0	48.0	48.0
C (〃)	42.0	42.0	42.0
CR	0.05	0.05	0.05
MG (mm/day)	2.0	2.0	2.0
WHC	not considering	constant with time	change with time

Lastly, **Fig. 16** shows the streamflows synthesized by combining the input of the daily snowmelts shown in **Fig. 15** with the runoff system model, compared with the observed data. Their agreement is good except for large floods. It is considered in this study that the subsurface and groundwater runoff components are dominant ones for streamflow hydrograph. If the excess over the saturated water content of melted water is directly added to the synthesized streamflow, the reproduction of hydrograph in the period of large floods will be improved. All of cases are evenly matched with the observed data.

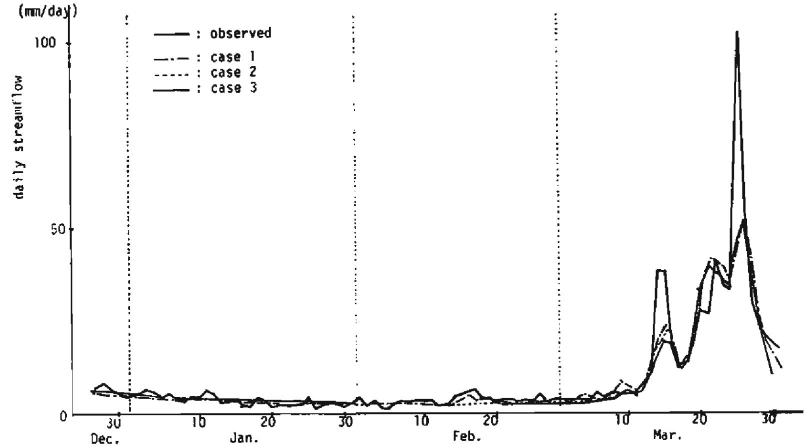

Fig. 16. Comparison among the synthesized and the observed mean daily streamflows at Kuzuryu dam in the snow accumulation and melting seasons.

5. Summary and conclusion

The snowmelt and runoff system models were developed on a continuous and daily basis for defining the snow accumulation and melting processes on as physical a basis as possible and at the same time best representing those processes in light of practical modelling considerations according to available data. These models were applied to the basin of Kuzuryu dam which has scarcely any data. It was concluded that those models could provide the following capabilities.

1) the depth of snow, the cumulative values of air temperature more or less than 0°C representing the melted and frozen energy, and rainfall in the area of higher elevations were estimated to a large extent through their simple correlation with elevation.

2) the heat transferred for snowmelting and freezing processes was introduced into the model in the appropriate form such as the variables *DM* and *DC*.

3) the possibility to estimate the daily snowmelt and streamflow with only a limited number of parameters such as γ, *C*, *CR* and *MG* was realized to some extent.

At the same time the following points were suggested for future work.

1) studies to establish a better understanding of whether the value of *WHC* is or not appropriate and how to set up the value.

2) studies to analyze the variables *DM* and *DC* in more detail.

3) investigation to establish whether the behaviour through the snowpack of melted water should be or not be modelled in different forms at the beginning and the maximum periods of snowmelt.

4) studies of the observation system and the introduction into a model of factors such as insolation, wind and humidity which will also influence snowmelt.

5) studies to extend the model developed to the late springtime in order to test the effect of recession of snow line.

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